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STRESS PROTEINS AND USES THEREFOR

Description

Related Applications

This application is a continuation-in-part of the corresponding International Application PCT/US94/06362, filed June 6, 1994 and U.S. Serial No. 08/073,381, filed June 4, 1993, which is a Continuation-in-Part of U.S. Serial No. 07/804,632 filed December 9, 1991, which is a File-Wrapper-Continuation of U.S. Application Serial No. 07/366,581 filed June 15, 1989, now abandoned, which is a Continuation-in-Part of U. S. Application Serial No. 07/207,298 filed June 15, 1988, now abandoned, and the corresponding International Application PCT/US89/02619 filed June 15, 1989. The teachings of PCT/US94/06362, U.S.S.N. 08/073,381, U.S.S.N. 07/804,632, U.S.S.N. 07/366,581, U.S.S.N. 07/207,298 and PCT/US89/02619 are incorporated herein by reference.

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Background of the Invention

Although the function of stress proteins is not entirely clear, it appears that some participate in assembly and structural stabilization of certain cellular and viral proteins, and their presence at high

concentrations may have an additional stabilizing effect during exposure to adverse conditions. Neidhardt, F.C. and R.A. Van Bogelen, In: Escherichia coli and Salmonella typhimurium, Cellular and Molecular Biology, (eds. Neidhardt, F.C., Ingraham, J.L., Low, K.B., Magasanik, B. Schaechter, M. and Umbarger, H.E. (Am. Soc. Microbiol., Washington, D.C.), pp. 1334-1345 (1987); Pelham, H.R.B. Cell, 46:959-961 (1986); Takano, T. and T. Kakefuda, Nature, 239:34-37 (1972); Georgopoulos, C. et al., New Biology, 239:38-41 (1972). Phagocytic host cells produce a hostile environment of foreign organisms, and the ability to produce stress proteins has been implicated in the survival of bacterial pathogens within macrophages Christman, M.F. et al., Cell, 41:753-762 (1985).

Mycobacterium (M.) tuberculosis and Mycobacterium (M.) leprae are the etiologic agents of tuberculosis and leprosy, respectively. These diseases afflict 20-30 million people and continue to present a significant global health problem. Joint International Union Against Tuberculosis and World Health Organization Study Group, Tubercle, 63:157-169 (1982); Bloom, B. and T. Godal, Rev. Infect Dis. 5:765-780 (1983). To develop more effective tools for the diagnosis and prevention of these diseases, it is important to understand the immune response to infection by mycobacterial pathogens.

The antibody and T-cell responses to infection or inoculation with killed mycobacteria have been studied in humans and in animals. Human patients with tuberculosis or leprosy produce serum antibodies directed against at least 12 mycobacterial proteins. Some of these proteins are also recognized by well-characterized murine monoclonal antibodies. Mice immunized with mycobacterial lysates produce antibodies that are directed predominantly to six M. tuberculosis and six M. leprae protein antigens. Engers, H.D. Infect. Immun., 48:603-605 (1985); Engers,

H.D., Infect. Immun., 51:718-720 (1986). Genes encoding these 12 mycobacterial antigens have been cloned, and recombinant proteins produced from these clones have been used to investigate the human T-lymphocyte response to mycobacterial infection. Husson, R.N. and R.A. Young, Proc. Natl. Acad. Sci., USA, 84:1679-1683 (1987); Young, R.A. et al., Nature, 316:450-452 (1985); Britton, W.J. et al., Lepr. Rev., 57, Suppl. 2, 67-75 (1986).

Protection against mycobacterial disease involves cell-mediated immunity. Joint International Union Against Tuberculosis and World Health Organization Study Group, Tubercle, 63:157-169 (1982); Hahn, H. and S.H.E. Kaufman, Rev. Infect. Dis., 3:1221-1250 (1981). T-lymphocytes cloned from patients or from volunteers immunized with killed mycobacteria have been tested for their ability to recognize the recombinant mycobacterial proteins. Lymphocyte-proliferation assays demonstrate that most of the antigens identified with monoclonal antibodies are involved in the T-cell response to mycobacterial infection or vaccination in mice and in humans. Limiting dilution analysis indicates that 20% of the mycobacterial-reactive $CD4^+$ T-lymphocytes in mice immunized with M. tuberculosis recognize a single protein, the 65-kDa antigen. Kaufman, S.H.E. et al., Eur J. Immunol., 17:351-357 (1987).

Summary of the Invention

The present invention relates to stress proteins and methods of modulating an individual's (such as a human, other mammal or other vertebrate) immune response. In particular, it relates to the use of such stress proteins in immune therapy or prophylaxis, which results in an induction or enhancement of an individual's immune response and as an immunotherapeutic agent which results in a decrease of an individual's response to his or her

own cells. In the embodiment in which an individual's immune response is induced or enhanced, the induced or enhanced response can be a response to antigens, such as those derived from a pathogen or cancer cell, or can be upregulation of the individual's immune status, such as in an immune compromised individual. In immune prophylaxis, stress proteins are administered to prevent or reduce the effects in an individual of a pathogen, which can be any virus, microorganism, parasite or other organism or substance (e.g., a toxin or toxoid) which causes disease or to prevent or reduce the effects in an individual of cancer cells. In preventing or reducing adverse effects of pathogens which contain stress proteins (e.g., bacteria, parasite, fungus) according to the method of the present invention, an individual's immune response to the pathogen's stress protein(s) is induced or enhanced through the administration of a vaccine which includes the pathogen's stress protein(s) or other stress proteins. The stress protein can be administered alone, as a member or component of a conjugate (e.g., joined to another antigen by chemical or recombinant means such as joined to a fusion partner resulting in a fusion protein), or as an adjuvant or carrier molecule to enhance or obtain a desired immune response to an antigen.

The present invention also relates to compositions which are conjugates comprised of a stress protein joined to another substance or component. For example, the present invention relates to a conjugate in which a stress protein is chemically linked to an antigen, or in which a stress protein is fused to an antigen (e.g., a fusion protein).

The present invention also relates to a method of generating monoclonal or polyclonal antibodies to a substance using a conjugate comprised of a stress protein joined to the substance. In this embodiment, an effective

amount of the conjugate (i.e., an amount which results in an immune response in the host) is introduced into a mammalian host which results in production of antibodies to the substance in the host. The antibodies are removed from the host and purified using known techniques (e.g., chromatography).

Preventing or reducing adverse effects of viral pathogens which do or do not contain stress proteins, as well as preventing or reducing the adverse effects of cancer cells according to the present method, is effected by enhancing an individual's immune surveillance system. Enhancement of immune response can be effected by modulating the immune cells by stimulation with a stress protein (e.g., a bacterial stress protein).

In the embodiment in which an individual's immune response is decreased, such as is used in treating autoimmune diseases, stress proteins known to be involved in the autoimmune response are administered to turn down an individual's immune response by tolerizing the individual to the stress proteins. Alternatively, the immune response to stress protein, which is known to occur in autoimmune disease, is reduced by interfering with the ability of immune cells which respond to stress proteins to do so.

A selected stress protein of the present invention can be administered to an individual, according to the method of the present invention, and result in an immune response which provides protection against subsequent infection by a pathogen (e.g., bacteria, other infectious agents which produce stress proteins) or reduction or prevention of adverse effects of cancer cells. Alternatively, a selected stress protein can be administered to an individual, generally over time, to induce immune tolerance against the selected stress protein. For example, a selected stress protein can be

administered in multiple doses over time in order to induce immune tolerance against an autoimmune disease such as rheumatoid arthritis.

Brief Description of the Drawings

Figure 1A is a graph illustrating the sequence similarity between portions of the M. tuberculosis 71-kDa antigen (residues 1-204; TB 71 kDa) and the E. coli DnaK protein (residues 430-639).

Figure 1B is a graph illustrating the sequence similarity between portions of the M. tuberculosis 65-kDa antigen (residues 1-540; TB 65 kDa) and the E. coli GroEL protein (residues 1-547).

Figure 2 is a comparison of the amino acid sequence of the human P1 protein (573 residues) (SEQ ID NO: 1) and the amino acid sequence of the groEL protein (547 residues) (SEQ ID NO: 2).

Figure 3 is a comparison of the amino acid sequence of the human P1 protein (573 residues) (SEQ ID NO: 1), which is a homolog of groEL protein, and the amino acid sequence of the 65 kDa M. leprae protein (540 residues) (SEQ ID NO: 3).

Figure 4 is a comparison of the amino acid sequence of the human P1 protein (573 residues) (SEQ ID NO: 1), which is a homolog of the groEL protein, and the amino acid sequence of the 65kDa M. tuberculosis protein (540 residues) (SEQ ID NO: 4).

Figure 5 is a schematic representation of selected stress protein fusion vectors which contain a polylinker with multiple cloning sites permitting incorporation of a gene of interest.

Figure 6 is a schematic representation of the stress protein fusion vector, pKS70 containing the T7 RNA polymerase promoter, a polylinker and the *mycobacterial*

tuberculosis hsp70 gene, and the stress protein fusion vector pKS72 containing the HIV p24 gag gene subcloned into the pKS70 vector.

Figure 7 is a graph illustrating the anti-p24 antibody titer in mice injected with the p24-hsp70 fusion protein, p24 alone and hsp70 alone.

Detailed Description of the Invention

Cells respond to a variety of stressful stimuli by increasing the synthesis of specific stress proteins. The most extensively studied cellular response to stressful stimuli is the synthesis of heat shock proteins (hsp) by a cell, induced by a sudden increase in temperature. Because many of the heat shock proteins are also induced by other stresses, they are frequently called stress proteins. Stress proteins and their relatives appear to help assemble and disassemble protein complexes. In bacteria, the major stress proteins, hsp70 and hsp60, occur at moderate levels in cells that have not been stressed but accumulate to very high levels in stressed cells. For example, hsp70 and hsp60 normally account for 1-3% of total E. coli protein, but can accumulate to about 25% under stressful conditions. Eukaryotic hsp70 and hsp60 proteins do not accumulate to these extreme levels. Their levels range from undetectable to moderately abundant, depending on the organism and cell type.

The present invention is based on the observation that stress proteins are among the major antigens available for presentation to T lymphocytes and may be common immune targets in a broad spectrum of infectious diseases. Immune responses to stress proteins are involved in immune surveillance by the body and a variety of different T cell types has been shown to recognize highly conserved stress protein determinants. Several observations, described below, suggest a model of immune

surveillance in which self-reactive T cells provide a first line of defense against infection or other invasion by pathogens, which include, but are not limited to, viruses, microorganisms, other organisms, substances such as toxins and toxoids, and agents which cause cell transformation, by recognizing and helping to eliminate stressed autologous cells, as well as cells infected with intracellular pathogens. Without wishing to be bound by this model, it is presented as one means by which it is possible to explain why prokaryotic and eukaryotic cells respond to a variety of potentially damaging stimuli, such as elevated temperature, by increasing the synthesis of a family of proteins, referred to as stress proteins, which are among the most highly conserved and abundant proteins found in nature.

Investigation of antigens involved in the immune response to the tuberculosis and leprosy bacilli (M. tuberculosis and M. leprae) initially led to the observation that a variety of stress proteins are among the major targets of the immune response, as is described at greater length below.

Further assessment has demonstrated that stress proteins may be common immune targets in a broad spectrum of infectious diseases. Sequence analysis has revealed 70-kDa heat shock protein homologues among major antigens of the protozoan parasites Plasmodium falciparum (Bianco, A.E. et al., Proc. Natl. Acad. Sci., USA, 83:8713-8717 (1986)) and Schistosoma mansoni (Hedstrom, R. et al., J. Exp. Med., 165:1430-1435 (1987)) and the malarial parasite Brugia malayi (Selkirk, M.E. et al., J. Cell Biochem., 12D:290 (1988)). Similarly, homologues of GroEL have been found among antigens involved in the immune response to Salmonella typhimurium and Coxiella (Vodkin, M.H. and J.C. Williams, J. Bacteriol, 170:1227 (1988)), as well as Bordetella pertussis (Del Giudice, G., et al., J. of Imm.,

150: 2025-2032 (1993)). The presence of stress proteins among major immune targets in a variety of human pathogens is support for the idea that the stress response may be a general component of infection and that stress proteins should be considered among candidates for subunit vaccines. All organisms respond to heat by inducing synthesis of heat shock proteins (hsp), which are a group of proteins. This response is the most highly conserved genetic system known and has been shown to occur in every organism, including microorganisms, plants and animals, investigated to date. Many of the characteristics of the response are common to all organisms and the hsp are among the most highly conserved proteins known. For example, hsp90 family and hsp70 family proteins are present in widely diverse organisms. The proteins in each family--even in such diverse organisms--show approximately 50% identity at the amino acid level and at the nonidentical residues, exhibit many similarities. Several of the proteins induced by heat are also induced by a variety of other stresses. The hsps or a closely related/similar protein are present in all organisms at normal temperatures and have been shown to have key functions in normal cell metabolism. Lindquist, S. and E.A. Craig, Ann. Rev. Genet., 22:631-677 (1988). Because the stress response is common to prokaryotes and eukaryotes and stress proteins are among the most highly conserved in sequence, it is reasonable to expect that an antigen from one pathogen could immunize against another pathogen. Exposure to foreign stress proteins early in life might, in fact, induce a degree a immunity to a variety of infectious agents. If so, this could provide an explanation for the observation that, for many pathogens, only a fraction of infected individuals actually acquire clinical disease.

The following is a description of the relationship which has been observed between stress proteins and the immune response to mycobacterial infection; of the observation and supporting information that stress proteins are immune targets in many infections by pathogens; of the role of stress proteins as immune targets in transformed cells; of recognition of the fact that the immune response to conserved stress protein determinants may play an important role in autoimmune pathology in rheumatoid arthritis, as well as in adjuvant arthritis; and of the role of stress proteins in immune surveillance, as well as a model proposed for immune surveillance in which self-reactive T cells provide a first line of defense against infection and cell transformation.

Mycobacterial Stress Proteins are Targets of the Immune Response

An intriguing relationship between stress proteins and the immune response to mycobacterial infection has been observed. A more detailed examination of stress protein determinants and immune response mechanisms is essential to understanding the relationship among stress proteins, infection, and immunity.

In view of the involvement of proteins of M. tuberculosis and M. leprae in humoral and cell-mediated immune responses and to establish the functions of these proteins in the mycobacterial cell, the DNA encoding several of the M. tuberculosis and M. leprae antigens have been sequenced. The results, discussed in Example 1, demonstrate that many of these mycobacterial protein antigens exhibit striking sequence similarity to known stress-induced proteins. Three of the M. leprae and two of the M. tuberculosis protein antigens studied have been shown to exhibit striking sequence similarity to known

stress proteins. For reasons discussed in Example 1, it is concluded that two of the M. leprae and two of the M. tuberculosis antigens are homologues of the E. coli DnaK and GroEL proteins.

In mice, immunization with mycobacterial lysates elicits antibody responses to at least six M. tuberculosis protein antigens and a similar number of M. leprae protein antigens. Monoclonal antibodies specific for these proteins have been used to isolate clones from λgt11 DNA expression libraries of M. tuberculosis and M. leprae. The sequence of the DNA clones revealed that mycobacterial hsp70 (alias 70 kDa antigen) and hsp60 (alias 65 kDa antigen, GroEL) were the major targets of the murine antibody response to both M. tuberculosis and M. leprae. Two additional hsp, an 18 kDa member of the small hsp family and a 12 kDa homologue of groES, were found among the M. leprae and M. tuberculosis antigens. Young, D.B., et al., Proc. Natl. Acad. Sci., USA, 85:4267-4270 (1988); Shinnick, T.M., et al., Nuc. Acids Res., 17:1254 (1989).

The mycobacterial stress proteins are among the immunodominant targets of both murine antibody and T cell responses. In one study which summarized results obtained from 10 laboratories, a collection of 24 murine monoclonal antibodies recognized 6 M. leprae proteins; 7 of these antibodies are directed against 6 different determinants in the M. leprae hsp60. Engers, H.D., et al., Infect. Immun., 48:603-605 (1985); Mehra, V., et al., Proc. Natl. Acad. Sci., USA, 83:7013-7017 (1986). In a similar study, 3 of 33 monoclonal antibodies raised against M. tuberculosis recognized the M. tuberculosis hsp60 protein. Engers, H.D., et al., Infect. Immun., 51:718-720 (1986). Finally, limiting dilution analysis indicates that 20% of the mycobacterial-reactive CD4+ T lymphocytes in mice immunized with M. tuberculosis recognize this antigen.

Kaufmann, S.H., et al., Eur. J. Immunol., 17:351-357 (1987).

Although a rigorous quantitative analysis of the human immune response to mycobacterial stress proteins has not yet been reported, mycobacterial stress proteins are recognized by human antibodies and T lymphocytes and the evidence suggests that these proteins are among the major targets of the human cell mediated immune response. Emmrich. F., et al., J. Exp. Med., 163:1024-1029 (1985); Mustafa, A.S., et al., Nature (London). 319:63-66 (1986); Oftung, F., et al., J. Immunol., 138:927-931 (1987); Lamb, J.R., et al., EMBO J., 6:1245-1249 (1987). T lymphocytes from patients with mycobacterial infection or from volunteers immunized with mycobacteria have been cloned and tested for their ability to recognize the mycobacterial stress proteins. In each of these studies, some fraction of the human T cell clones were shown to recognize one or more of the mycobacterial stress proteins.

Stress Proteins are Immune Targets in Infections by Pathogens

The observation that stress proteins are important targets of the immune response to mycobacterial infection and the knowledge that the major stress proteins are conserved and abundant in other organisms suggested that stress proteins are likely to be immune targets in many infections by pathogens. Indeed, that is now clearly the case. Antigens from a wide variety of infectious agents have been identified as members of stress protein families. The major stress protein antigen recognized by antibodies in bacterial infections is hsp60. "Common antigen", an immunodominant protein antigen long known to be shared by most bacterial species, turns out to be hsp60. Shinnick, T.M., et al., Infect. Immun., 56:446

(1988); Thole, J.E.R., et al., Microbial Pathogenesis, 4:71-83 (1988). Stress proteins have also been identified as immune targets in most major human parasite infections. Bianco, A.E., et al., Proc. Natl. Acad. Sci. USA, 83:8713 (1986); Nene, V., et al., Mol. Biochem. Parasitol., 21:179 (1986); Ardeshir, F., et al., EMBO J., 6:493 (1987); Hedstrom, R., et al., J. Exp. Med., 165:1430 (1987); Selkirk, M.E., et al., J. Cell Biochem., 12D:290 (1988), Engman, D.M., et al., J. Cell Biochem., 12D: Supplement, 290 (1988); Smith, D.F., et al., J. Cell Biochem., 12D:296 (1988). Antibodies to hsp70 have been identified in the sera of patients suffering from malaria, trypanosomiasis, leishmaniasis, schistosomiasis and filariasis. Hsp90 is also a target of antibodies in trypanosomiasis and a member of the small hsp family is recognized in some patients with schistosomiasis.

Proteins homologous to stress proteins have also been identified in viruses. Recently, a protein encoded by the RNA genome of the Beet Yellows Closterovirus, a plant virus, has been shown to be homologous to hsp70. Agranovsky, A.A., et al., J. Mol. Biol., 217: 603-610 (1991). In addition, stress protein induction occurs in eukaryotic cells following infection by diverse viruses in vitro. Collins, P.L., and Hightower, L.E., J. Virol., 44:703-707 (1982); Nevins, J.R., Cell, 29:913-939 (1982); Garry, R.F. et al., Virology, 129:391-332 (1988); Khandjian, E.W. and Turler, H., Mol. Cell Biol., 3:1-8 (1983); LaThangue, N.B., et al., EMBO J., 3:267-277 (1984); Jindal, S. and Young, R., J. Viral, 66:5357-5362 (1992). CTL that recognize these neo-antigens could limit the spread of virus by killing infected cells, possibly before substantial amounts of mature virus are assembled, and by secreting the lymphokine γ-interferon. Pestka, S., in: Methods Enzymol., Interferons, Part A., Vol. 79 Academic Press, New York, pp. 667 (1981). Evidence

consistent with this idea is emerging. Koga et al., (1989) have shown that infection of primary murine macrophages with CMV rendered them susceptible as targets for MHC-I restricted $CD8^+$ CTL specific for linear epitopes of M. tuberculosis hsp60. Koga, T., et al. (1989). Although the epitope recognized by these CTL on infected macrophages was not defined, it is tempting to speculate that a cross-reactivity with self hsp60 epitopes is being observed. Indeed, the same groups showed that a homologous hsp60 is constitutively present in macrophages and is upregulated by γ-interferon stimulation.

Stress Proteins as Immune Targets in Transformed Cells

Stress proteins appear to be produced at high levels in at least some transformed cells. Bensaude, O. and Morange, M., EMBO J., 2: 173-177 (1983). An 86 kDA murine tumor antigen has been found to be homologous to representatives of the hsp90 family in yeast and Drosophila. Ullrich, S.J., Proc. Natl. Acad. Sci., USA, 83: 3121-3125 (1986). Immunization of mice with the purified protein led to inhibition of tumor growth in 95% of experimental animals that had been seeded with cultured tumor cells. All of the protected mice had high titers of anti-hsp90 serum antibody which was able to precipitate murine hsp90 from lysates of heat shocked mouse embryo cells. Again, a role for autoreactive lymphocytes is implied, since T cells capable of recognizing autologous cells stressed by transformation could help eliminate nascent tumor cells.

Stress Proteins and Autoimmune Processes

Rheumatoid arthritis is characterized by a chronic proliferative and inflammatory reaction in synovial membranes which is thought to involve autoimmune

processes. Rat adjuvant arthritis resembles human rheumatoid arthritis in many respects, and has been used as an experimental animal model for human disease. Pearson, C.M., Arthritis Rheum., 7:80-86 (1964). Adjuvant arthritis can be induced in rats with a single intradermal injection of killed M. tuberculosis in complete Freund's adjuvant. An autoimmune process involving T lymphocytes appears to be responsible for the generation of the disease. Holoshitz, J., et al., Science, 219:56-58 (1983). T cell lines isolated from the draining lymph nodes of arthritic rats and propagated in vitro by stimulation with M. tuberculosis-pulsed syngeneic antigen presenting cells can cause a transient form of the disease when transferred to irradiated rats. Since care was taken in these experiments to exclude the transfer of contaminating M. tuberculosis, this result strongly suggests that the clinical effects of the disease are a consequence of an autoimmune reaction in which the autoantigen is shared with M. tuberculosis.

The rat and M. tuberculosis antigens recognized by the arthritogenic T cells have been sought for a number of years. A number of different proteins present in synovial membranes have been proposed to be the cross-reactive rat antigen, but were later discounted as procedures for the purification of these proteins improved. van Eden, W., et al., Proc. Natl. Acad. Sci., USA, 82:5117-5120 (1985); Holoshitz, J., et al., Science, 219:56-58 (1983). The M. tuberculosis antigen recognized by the arthritogenic T cells was recently shown to be a 65 kDa protein (van Eden, W., et al., Nature, 331:171 (1988), which has now been shown to be hsp60 (see the Example 1). Using a combination of truncated recombinant 65 kDa proteins and peptides, a nine amino acid epitope of hsp60 has been identified as the minimum stimulatory sequence for arthritogenic T cell clones in proliferation assays. Now

that it is clear that some arthritogenic T cells recognize the mycobacterial hsp60, it is quite possible that the rat autoantigen is also hsp60.

The results obtained in the adjuvant arthritis model led investigators to determine whether T lymphocytes from human rheumatoid arthritis patients also recognize mycobacterial antigens. These investigators have found not only that patients with rheumatoid arthritis have T cells that recognize M. tuberculosis antigens, but that these T cells have diverse phenotypes. Substantial proliferative responses to mycobacterial extracts are observed with uncloned T cells (predominantly $CD4^+$) from both synovial infiltrates and peripheral blood, although responses are generally greater in synovial infiltrates. Abrahamson, T.G., et al., Scand. J. Immunol., 7:81-90 (1978); Holoshitz, J., et al., Lancet ii, 305-306 (1986). Holoshitz et al. found that 4 of 5 T cell clones isolated from human rheumatoid synovia which respond to M. tuberculosis antigens were $CD4^-$ $CD8^-$ cells with γ/δ T cell receptors. Holoshitz, J., et al., Nature, 339:226-229 (1989). This observation is interesting because γ/δ T cells have yet to be assigned a role in immunity. One of the γ/δ clones was tested for its ability to respond to purified mycobacterial hsp60 and was found to be positive in proliferation assays. Due to the conserved nature of stress proteins, these T cells have the potential for autoreactivity. Lamb and coworkers have shown that polyclonal T cells from synovial infiltrates recognize both mycobacterial hsp60 and hsp70. Lamb, J.R., et al., Intl. Immunol., in press (1989). The population of T cells that recognize the mycobacterial stress proteins were shown to respond to E. coli hsp60 and hsp70 and, most interestingly, human hsp70 purified from heat shocked macrophages. Thus, immune responses to conserved stress

protein determinants, perhaps initiated by bacterial infection (not necessarily by mycobacteria), may play an important role in autoimmune pathology in rheumatoid arthritis, as well as in adjuvant arthritis.

Stress Proteins and Immune Surveillance

A variety of different T cell types has now been shown to recognize highly conserved stress protein determinants. The ability of cells to respond to stress by increasing the levels of the highly conserved stress proteins; the presence of T cells of diverse phenotypes in healthy individuals that are capable of recognizing self stress protein determinants; and observations that stress responses are induced by pathogenic infections and by cell transformation, all suggest a model of immune surveillance in which self-reactive T cells provide a first line of defense against infection and transformation by recognizing and helping to eliminate stressed autologous cells, as well as cells infected with intracellular pathogens. The pool of lymphocytes that recognize conserved stress protein determinants might be induced during establishment of natural microbial flora on the skin and in the gut, and maintained by frequent stimulation by pathogens, such as bacteria and viruses, as well as other stressful stimuli encountered during a normal lifetime. This model is attractive because it provides a way in which the immune system could exploit the existence of conserved epitopes in stress proteins to respond immediately to antigenically diverse pathogens and cellular changes, producing an initial defense that need not await the development of immunity to novel antigens.

The lymphocytes which recognize conserved stress protein determinants must be capable of discriminating

between normal and stressed cells. Since many stress proteins are constitutively expressed in normal cells, although at lower levels than in stressed cells, the potential for autoreactivity is ever-present. Normal cells may escape destruction by expressing only substimulatory levels of stress protein determinants on their surfaces. In addition, stress proteins may only be processed and presented during stress, and it may be relevant that many stress proteins have altered intracellular locations during stress. Finally, immune regulatory networks may prevent activation of autoreactive T cells under normal conditions. The regulatory constraints required by this system might occasionally break down, perhaps during stress caused by bacterial or viral infections, leading to autoimmune disease. Rheumatoid arthritis may be such a disease.

Modulation of Immune Response

The precise relationship between stress proteins and the host immune response to infection is as yet undefined. When cells are subjected to a variety of stresses, they respond by selectively increasing the synthesis of a limited set of stress proteins. Some stress proteins, including the products of DnaK and GroEL, are major constituents of the cell under normal growth conditions and are induced to even higher levels during stress. Lindquist, S., Annu. Rev. Biochem. 55: 1151-1191 (1986); Neidhardt, F.C. and R.A. VanBogelen, In Escherichia coli and Salmonella Typhimurium, Cellular and Molecular Biology, (eds. Neidhardt, F.C., Ingraham, J.L. Low, K.B. Magasanik, B. Schaechter, M. and Umbarger, H.E.) Am. Soc. Microbiol., Washington, D.C., pp. 1134-1345 (1987). It has now been demonstrated that stress-related proteins are targets of the immune response. Young, D. et al., Proc. Natl. Acad. Sci. USA, 85:4267-4270 (1988). It is

reasonable to expect that immunodominant antigens would be found among such abundant proteins, as has now been shown to be the case.

According to the method of the present invention, it is possible to modulate the immune response in an individual, such as a human, other mammal or other vertebrate, by altering the individual's response to stress proteins. In particular, it is possible to enhance or induce an individual's response to a pathogen (e.g., bacteria, virus, parasites, or other organism or agent, such as toxins, toxoids) or to cancer cells or enhance or induce an upregulation of an individual's immune status (such as in an immune compromised individual or HIV-infected individual); and to decrease an individual's autoimmune response, such as occurs in some forms of arthritis. In addition, administration of a stress protein using the method of the present invention provides protection against subsequent infection by a pathogen. As demonstrated herein, stress proteins contain regions of highly conserved amino acid sequences and have been shown to be major immunodominant antigens in bacterial and other infections. Therefore, it is reasonable to expect stress proteins can be used to elicit strong immune responses against a variety of pathogens. The stress protein administered to induce or enhance an immune response to pathogens can be the stress protein of the pathogen against which an immune response is desired or other stress protein, a portion of that protein of sufficient size to stimulate the desired immune response or a protein or amino acid sequence which is the functional equivalent of the stress protein in that it is sufficiently homologous in amino acid sequence to that of the stress protein to be capable of eliciting the desired response (an immune response substantially similar to that which occurs in response to the stress protein) in the

individual to whom it is administered. The term "sufficiently homologous in amino acid sequence to that of the stress protein" means that the amino acid sequence of the protein or polypeptide will generally show at least 40% identity with the stress protein amino acid sequence; in some cases, the amino acid sequence of a functional equivalent exhibits approximately 50% identity with the amino acid sequence of the stress protein.

Any stress-induced proteins or their functional equivalents can be used by the present invention to enhance or induce an immune response in an individual (e.g. a human, other mammal or vertebrate), against an infection by a pathogen, for immunotherapy against cancer cells, for generally upregulating an individual's immune status and for use in inducing immune tolerance in an individual or animal.

The stress proteins of the present invention can be administered in a variety of ways to modulate the immune response of an individual (e.g., a human, other mammal or other vertebrate). In one embodiment, the stress protein is administered as a vaccine which is comprised of the stress protein or a portion of the stress protein which is of sufficient size to stimulate the desired immune response. In this embodiment, the vaccine can be a "specific vaccine" which contains a specific stress protein of a particular pathogen against which an immune response is desired, such as a bacterial stress protein. In this case, since the pathogen's stress proteins are distinguishable from those of the host, it is possible to induce an immunoprophylactic response specific to the pathogen's stress proteins. Blander, S.J., et al., J. Clin. Invest., 91:717-723 (1993). This can be carried out by administering a vaccine which includes all or a portion (e.g., sufficient amino acid sequence to have the desired stimulatory effect on immune response) of the pathogen's

stress protein or of another protein having an amino acid sequence sufficiently similar to that of the stress protein sequence to stimulate the immune response to the pathogen's stress protein. Alternatively, in the case of a pathogen which does not contain stress proteins, (e.g. some viruses) or in the condition of neoplasia, stress proteins or highly conserved stress protein determinants, such as those shown to be recognized by a variety of T cells, can be administered as a type of "general" vaccine to achieve an upregulation of the immune response. Administration of such a vaccine will enhance the existing immune surveillance system. For instance, a vaccine which includes a bacterial, or other stress protein can be administered to enhance the immune system which will result in an immune response against a pathogen which does not contain stress proteins. Alternatively, this type of "general" vaccine can be used to enhance an individual's immune response against cancer or to generally upregulate an individual's immune status, such as in an immune compromised individual (e.g., an individual undergoing chemotherapy or an HIV-infected individual). In either case of this embodiment (specific or general vaccine), the immune response to the stress protein sequence will be increased and effects of the pathogen, disease condition or immune impairment will be reduced (decreased, prevented or eliminated).

In another embodiment, stress proteins can be used to enhance immune surveillance by applying local heat or any other substances or changes in condition which induce the stress response in the individual being treated. (This can also be employed in conjunction with the specific vaccine, described previously, administered to enhance an immune response to a stress protein-containing pathogen or in conjunction with the general vaccine, described above, administered to enhance the immune response against a

pathogen which does not contain its own stress proteins, cancer, or to upregulate the immune status of an individual). For example, it is known that increased levels of stress proteins are produced in many types of cancer cells. Therefore, enhancement of the immune surveillance system, using this embodiment of the present invention as described, can be used to facilitate destruction and/or to prevent progression or establishment of cancer cells.

The method of the present invention can also be used to modify or modulate an individual's response to his or her own cells (e.g., as in autoimmune diseases). There are at least two ways in which the present invention can be used immunotherapeutically. First, stress proteins, such as heat shock proteins (e.g., hsp 70 and hsp60), are known to be involved in autoimmune disease. It is, thus, possible to turn down an individual's immune response, resulting in the individual becoming more tolerant of the protein. Second, because it is known that under some circumstances, one component of the immune response in certain autoimmune diseases can be to stress proteins, it is possible to selectively inhibit or interfere with the ability of immune cells which normally interact with such proteins to do so. This can be done, for example, by administering monoclonal antibodies that bind to specific T cell receptors and delete or disable such cells. Alternatively, rather than knocking out immune cells, the stress response in cells can be turned down by administering a drug capable of reducing a cell's ability to undergo the stress response. For example, a drug targeted to or specific for heat shock transcription factor, which is needed to stimulate heat shock genes, can be administered. The transcription factor is rendered nonfunctional or subfunctional and, as a result, cells' ability to undergo the stress response is also lessened.

In another embodiment of the present invention, the stress protein is administered as a vaccine which is comprised of two moieties: a stress protein and another substance (referred to as an antigen, e.g. protein, peptide, carbohydrate, lipid, organic molecule) against which an immune response is desired. The two moieties are conjugated or joined to form a single unit. Conjugation can be achieved by chemical means known to those skilled in the art (e.g. through a covalent bond between the stress protein and the second moiety; reductive amination) or, as demonstrated in Example 2, by recombinant techniques. If recombinant techniques are used to produce the conjugate, the result is a recombinant fusion protein which includes the stress protein and the antigen in a single molecule. This makes it possible to produce and purifiy a single recombinant molecule in the vaccine production process. In this embodiment, the stress protein can be seen to act as an adjuvant-free carrier, and it stimulates strong humoral and T cell responses to the substance to which the stress protein is fused. The stress protein can be conjugated to any substance against which an immune response is desired or to a portion of the substance sufficient to induce an immune response in an individual to whom it is administered. The substance includes but is not limited to proteins (e.g., ovalalbumin, Influenza virus Hemagglutinin, Human Immunodeficiency Virus p24), peptides (e.g., Human Immunodeficiency Virus peptides, melanoma antigen peptides), oligosaccharides (e.g., Neiserria meningitidis group B, Streptococcus pneumoniae type 14, Hemophilis influenzae type b), lipids, carbohydrates (e.g., glycolipid antigens in human cancers such as GD3, GM2, Gb3, Forssman antigen, Sialosyl-Le^a antigen and glycoprotein antigens in human cancers such as CEA, AFP,

PSA, Tn antigen), organic molecules or a combination thereof. Recent evidence demonstrating the effectiveness of such a vaccine indicates that mycobacterial hsp70 proteins when conjugated to other proteins act as adjuvant-free carriers. The humoral immune response to some peptides conjugated to mycobacterial hsp70 administered without any adjuvant was very similar to the antibody response to the same peptides administered in Freund's complete adjuvant. Lussow, A.R., et al., Eur. J. Immun., 21:2297-2302 (1991). Barrios, C. et al., Eur. J. Immun., 22:1365-1372 (1992).

The present invention also relates to compositions which are conjugates comprised a stress protein joined to another substance or component. For example, the present invention relates to a conjugate in which a stress protein is chemically linked to an antigen, or in which a stress protein is fused to an antigen (e.g., a fusion protein).

As demonstrated in Example 3, the HIV p24 gag gene was subcloned into the stress protein fusion vector pKS70 (Figure 6), containing the T7 RNA polymerase promoter, a polylinker and the *mycobacterial tuberculosis* hsp70 gene. The resulting vector pKS72 (Figure 6) was used to produce the p24-hsp70 fusion protein in *E. coli*. Adjuvant-free, purified p24-hsp70 fusion protein was injected into Balb/c mice and as shown in Figure 7, the anti-p24 antibody titer was 2.7 orders of magnitude higher in mice injected with the p24-hsp70 fusion protein than in mice injected with p24 alone or hsp70 alone. Mice injected with p24 and the adjuvant, alum, also produced an antibody response to p24. Finally, a demonstrable T cell response was seen in mice injected with the p24-hsp70 fusion protein and in mice injected with p24 alone.

In another embodiment of the present invention, the stress protein or a portion of the stress protein which is of sufficient size to stimulate an immune response or an

equivalent, is administered as an adjuvant, with another substance (referred to as an antigen) against which an immune response is desired. The stress protein can be used as an adjuvant with any substance or antigen against which an immune response is desired or to a portion of the substance sufficient to induce an immune response in an individual to whom it is administered. The substance includes proteins, peptides, oligosaccharides, lipids, carbohydrates, organic molecules or a combination thereof. Via linkage to a stress protein, strong and specific B and T cell mediated immunity can be generated in a mammalian host (e.g., mice, rabbits, humans) to virtually any organic molecule. This is particularly useful 1) with substances (e.g., antigens) which alone are non-immunogenic; 2) when adjuvants cannot be used or do not work well in combination with a particular antigen; 3) when the availability of purified antigen is limited, particularly with fusion proteins where the antigen is made using recombinant DNA technology; 4) where other carrier molecules, such as KLH, BSA, OVA or thyrogloulin, which additionally require adjuvants, are not effective or desirable; 5) there is a genetic restriction in the immune response to the antigen; 6) there is a pre-existing immunosuppression or non-responsiveness to an antigen (e.g., pediatric vaccines where infants and children under 2 years of age do not generate protective immunity to carbohydrate antigens well); and 7) the type of immune response achieved by other carriers or adjuvants is undesirable or ineffectual (i.e., stress protein conjugates could be used to bias toward either B or T cell immunity via proper dose, route and inoculation regimen).

The present invention also relates to a method of generating monoclonal or polyclonal antibodies to a substance using a conjugate comprised of a stress protein joined to the substance. In this embodiment, an effective

amount of the conjugate (i.e., an amount which results in an immune response in the host) is introduced into a mammalian host which results in production of antibodies to the substance in the host. The antibodies are remvoed from the host and purified using known techniques (e.g., chromatography), thereby resulting in production of polyclonal antibodies. Alternatively, the antibodies produced using the method of the present invetion can be used to generate hybridoma cells which produce monoclonal antibodies using known techniques (Kohler, G., et al., Nature, 256:495(1975) Milstein et al., Nature, 266:550-552(1977); Koprowski et al., Proc. Natl. Acad. Sci, 74:2985-2988 (1977); Welsh, Nature, 266:495(1977); Maniatis, T. et al., Molecular Cloning, A Laboratory Manual, Cold Spring Harbor Lab., Cold Spring Harbor, NY (1982)).

The stress protein, stress protein portion, stress protein functional equivalent and the substance to which the stress protein is fused or conjugated present in the vaccine can be produced or obtained using known techniques. For example, the stress protein or stress protein portion can be obtained (isolated) from a source in which it occurs in nature, can be produced by cloning and expressing a gene encoding the desired stress protein or stress protein portion or can be synthesized chemically or mechanically.

An effective dosage of the stress proteins of the present invention as vaccines or adjuvants, to elicit specific cellular and humoral immunity to stress proteins, or to substances conjugated to the stress proteins, such as proteins or oligosaccharides, is in the range of 0.1 to 1000 ug hsp per injection, depending on the individual to whom the stress protein is being administered. Lussow, A.R., et al., Eur. J. Immun., 21:2297-2302 (1991). Barrios, C. et al., Eur. J. Immun., 22:1365-1372 (1992). The appropriate dosage of the stress protein for each

individual will be determined by taking into consideration, for example, the particular stress protein being administered, the type of individual to whom the stress protein is being administered, the age and size of the individual, the condition being treated or prevented and the severity of the condition. Those skilled in the art will be able to determine using no more than routine experimentation, the appropriate dosage to administer to an individual.

Various delivery systems can be used to administer an effective dose of the vaccine of the present invention. Methods of introduction include, for example, intradermal, intramuscular, intraperitoneal, intravenous, subcutaneous, intranasal, epidural and oral routes. Any other convenient route of administration can be used (infusion of a bolus injection, infusion of multiple injections over time, absorption through epithelial or mucocutaneous linings such as, oral mucosa, rectal and intestinal mucosa) or a series of injections over time.

The present invention is further illustrated by the following exemplification, which is not intended to be limiting in any way.

EXEMPLIFICATION

EXAMPLE 1 Isolation and Characterization of Mycobacterial Stress Protein Antigens

Recombinant DNA Clones. The isolation and characterization of *M. tuberculosis* and *M. leprae* λgt11 genomic DNA clones with murine monoclonal antibodies have been described. Husson, R.N. and Young, R.A., *Proc. Natl. Acad. Sci., USA* 84: 1679-1683 (1987); Young, R.A., *et al.*, *Nature* (London) 316: 450-452 (1985). DNA was isolated

from these clones and was manipulated by standard procedures. Davis, R.W., Advanced Bacterial Genetics: A Manual for Genetic Engineering (Cold Spring Harbor Lab., Cold Spring Harbor, NY), (1980).

DNA Sequence Analysis. DNA was subcloned into vector M13mp18 or M13mp19 (New England Biolabs), as suggested by the supplier. Dideoxynucleotide chain-termination reactions and gel electrophoresis of the sequenced produced were as described. Davis, R.W., Advanced Bacterial Genetics: A Manual for Genetic Engineering (Cold Spring Harbor Lab., Cold Spring Harbor, NY), (1980). DNA sequences were determined for both strands of DNA. Computer analysis of sequences with UWGCG programs was as described by Devereux, J., et al., Nucleic Acids Res., 12: 387-395 (1984).

Immunoblot Analysis. Escherichia coil strain TG1 was transformed with the following plasmids by standard procedures (Maniatis, T., et al., Molecular Cloning, A Laboratory Manual (Cold Spring Harbor Lab., Cold Spring Harbor, NY) (1982), with selection for ampicillin resistance: pND5, a derivative of pBR325 containing the E. coli GroEL genes (Jenkins, A.J., et al., Mol. Gen. Genet., 202: 446-454 (1986); pUC8 (Vic, J., Gene, 19: 259-268 (1982); pUC8 with insert DNA for λgtll clone Y3178 (M. leprae 65-kDa antigen, Young, R.A., et al., Nature, (London) 316: 450-452 (1985)) ligated in the EcoRI site.

Overnight cultures of E. coli strains in Luria-Bertani (LB) medium were centrifuged and resuspended in isotonic phosphate-buffered saline at a cell density corresponding to an absorbance of 2 at 600 nm. An equal volume of sample buffer containing 2% (wt/vol) $NaDodSo_4$ was added, and, after heating on a boiling water bath for 2 min, samples were electrophoresed on 12% (wt/vol) polyacrylamide gels in the presence of $NaDodSO_4$. Blots

were prepared by electrophoretic transfer of the proteins to a nitrocellulose membrane, and binding of monoclonal antibodies was assayed with a peroxidase-conjugated secondary antibody as described. Young, D.B., et al., Infect. Immun., 55: 1421-1425 (1987).

Six M. tuberculosis and six M. leprae proteins have been implicated in the immune response to the mycobacterial pathogens (Table 1). To obtain clues to the normal cellular function of several of these mycobacterial antigens, DNA clones encoding these proteins, isolated by using monoclonal antibodies to probe lambda gtll libraries (Husson, R.N. and Young, R.A., Proc. Natl. Acad. Sci., USA, 84: 1679-1683 (1987); Young, R.A., et al., Nature, (London) 316: 450-452 (1985)) were subjected to sequence analysis. The sequences elucidated have been submitted to the GenBank sequence database.

The Mycobacterial 71-k Da Antigen. The 71-k Da antigen of M. tuberculosis is recognized by human T cells during infection (Table 1).

TABLE 1

MYCOBACTERIAL PROTEIN ANTIGENS

Protein, kDA	Recognized by Human T Cells	Subjected to sequence analysis	Homology with known proteins
M. tuberculosis			
71	+	+	DnaK
65*	+	+	GroEL
38	+	-	-
19	+	+	None
14	+	-	-
12	ND	-	-
M. leprae			
70	ND	-	DnaK
65	+	+	GroEL
36	+	-	-
28	+	-	-
18	+	+	Plant Hsp
12	ND	-	-

Mycobacterial protein antigens, their recognition by human T cells, and homology of the deduced mycobacterial protein sequences to known proteins are summarized. ND, not determined; +, yes; -, no

* Includes data derived from study of the 65-kDA antigens of M. bovis BCG (Bacillus Calmette-Gurein), which is identical to the M. tuberculosis 65-kDA antigen.

\+ A.S. Mustafa, J.R. Lamb, D. Young and R.A. Young, unpublished data.

The insert DNA of lambdagtll clone Y3271 (Husson, R.N., et al., Proc. Natl. Acad. Sci, USA, 84: 1679-1683 (1987), was sequenced to obtain amino acid sequence information for the 71-kDa antigen of M. tuberculosis. This clone produces a beta-galactosidase fusion protein containing the carboxyl-terminal one-third of the 71-kDa antigen exhibiting 40% amino acid sequence identity with the comparable segment of the dnaK gene product from E. coli (Bardwell, J.C., et al., Proc. Natl. Sci., USA, 81: 848-852 (1984)), (Fig. 1). Figure 1A shows the extent of sequence similarity between portions of the mycobacterial and the E. coli 70-k Da polypeptides. Sequences transcriptionally downstream from the mycobacterial 71-k Da gene predict a 356-amino acid protein homologous to the E. coli dnaJ gene product (unpublished data), indicating that the E. coli dnaK-dnaJ operon structure is conserved in M. tuberculosis and consistent with the conclusion that the mycobacterial 71-kDa antigen is a homologue of the E. coli dnaK gene product. The product of the dnaK gene is a member of the 70-kDa heat shock protein family that is highly conserved among prokaryotes and eukaryotes (Bardwell, J.C., et al., Proc. Natl. Acad. Sci., USA, 81: 848-852 (1984); Lindquist, S., Annu. Rev. Biochem., 55: 1151-1191 (1986).

The M. leprae 70-k Da antigen cross-reacts with monoclonal antibodies directed to the M. tuberculosis 70-kDa antigen. M. tuberculosis and M. leprae are both members of the 70-k Da heat shock protein family of stress proteins.

The mycobacterial 65-kDa antigen. The 65-kDa antigens of M. tuberculosis and M. leprae are involved in the human T-cell response to mycobacterial infection (Table 1). Genes encoding these proteins have been isolated (Husson, R.N., and Young, R.A., Proc. Natl. Acad. Sci., USA, 84: 1679-1683 (1987); Young, R.A., et al.,

Nature, (London) 316: 450-452 (1985)) and sequenced (Shinnick, T.M., J. Bacteriol., 169: 1080-1088 (1987); Mehram, V., et al., Proc. Natl. Acad. Sci., USA 83: 7013-7017 (1986)), revealing that the amino acid sequences of the 65-kDa antigens of M. tuberculosis (SEQ ID NO: 4) and M. leprae (SEQ ID NO: 3) are 95% identical. These proteins sequences exhibited no significant sequence similarity to proteins in the GenBank database.

Identification of these proteins was based on the observation that some monoclonal antibodies directed against the mycobacterial 65-kDa antigens cross-react with an E. coli protein of 60kDa. E. coli cells transformed with the plasmid pND5 (Sanger, F., et al., Proc. Natl. Acad. Sci., USA 74: 5463-5467 (1977), which contains the E. coli gro E genes, had been shown to accumulate large amounts of the 60-kDa protein. A comparison of the mycobacterial 65-kDa protein sequences with those determined for E. coli groEl (C. Woolford, K. Tilly, C. Georgopoulous, and R.H., unpublished data) revealed the extent of the sequence similarity as shown in Figure 1B.

The 60-kDa Gro EL protein is a major stress protein in E. coli. Lindquist, S., Annual. Rev. Biochem., 55: 1151-1191 (1986); Nature, 333: 330-334 (1988). There is some evidence that the mycobacterial 65-kDa proteins accumulate in response to stress: Mycobacterium bovis BCG (bacillus Calmette-Guerin) cultures grown in zinc-deficient medium are substantially enriched in this protein (De Bruyn, J., et al., Infect. Immun. 55: 245-252 (1987)). This infers that the 65-kDa proteins of M. tuberculosis and M. leprae are homologues of the E. coli Gro EL protein.

Other Mycobacterial Antigens. T lymphocytes that respond to the M. tuberculosis 19-kDa antigen and the M. leprae 18-kDa antigen have been observed in humans with tuberculosis and leprosy, respectively (Table 1). DNA

encoding these antigens was sequenced from the λgt11 clones Y3148 (Husson, R.N. and Young, R.A., Proc. Natl. Acad. Sci., USA 84: 1679-1683 (1987); and Y3179 (Young, R.A., et al., Nature, (London) 316: 450-452 (1985)), respectively. The M. tuberculosis 19-kDa protein sequence predicted from the DNA exhibited no significant sequence similarity to proteins in the GenBank database.

However, the M. leprae 18-kDa protein sequence was similar to the soybean 17-kDa protein heat shock protein, a protein representation of a major class of plant heat shock proteins (Schoffl, F. and Van Bogelen, R.A., In: Escherichia coli and Salmonella typhimurium, Cellular and Molecular Biology, Am. Soc. Microbiol., Washington, D.C. (1987).

EXAMPLE 2 Construction of Stress Protein-Fusion Vaccines for Use as Adjuvant-Free Carriers in Immunizations

Recombinant Fusion Vectors. A series of stress protein fusion vectors for use in E. coli were constructed and are shown in Figure 5. These vectors contain the T7 RNA polymerase promoter fused to the M. bovis BCG hsp70 gene or the M. bovis BCG hsp60 gene. The vectors also contain a polylinker with multiple cloning sites, permitting incorporation of a gene of interest so that the antigen encoded by that gene is expressed as a fusion protein with the stress protein. A subset of these vectors permit incorporation of the foreign gene with a coding sequence for a C-terminal 6-Histidine "tag" for ease of fusion protein purification. Thus far, recombinant clones have been generated that produce hsp70 proteins fused to HIV gag and HIV pol proteins.

Purification of stress protein fusions. Two strategies have been developed to purify the recombinant fusion proteins. The T7 system usually produces such large amounts of protein that it forms inclusion bodies, permitting purification by centrifugation. The preliminary results indicate that an hsp70-HIV gag fusion protein accounts for about 20% of total E. coli protein in the T7 system. If necessary, other fusion proteins can be purified via the 6-Histidine "tag".

EXAMPLE 3 ADJUVANT-FREE CARRIER EFFECT OF HSP70 *IN VIVO*

The stress protein fusion vector pKS70 (figure 6), containing the T7 RNA polymerase promoter, a polylinker and the *mycobacterial tuberculosis* hsp70 gene, was constructed. The HIV p24 gag gene was subcloned into pKS70 using the NdeI and BamHI sites and the resulting pKS72 vector (Figure 6) was used to produce the p24-hsp70 fusion protein in *E. coli*. The fusion protein was purified as inclusion bodies and further purified using ATP-agarose chromatography and MonoQ ion exchange chromatography.

The p24-hsp70 protein in phosphate buffered saline (PBS), in the absence of an adjuvant, was injected intraperitoneally into Balb/c mice. As controls, the p24 protein alone in PBS or the hsp70 protein alone in PBS was injected into different groups of mice. Three weeks later, the mice were boosted and finally, three weeks after the boost, the mice were bled. The anti-p24 antibody titer was then determined by ELISA. Mice injected with 25 pmoles of p24-hsp70 had antibody levels 2.7 orders of magnitude higher than mice injected with p24 alone or hsp70 alone (Figure 7). Results of experiments in which mice were injected with p24 and the adjuvant, alum, also showed that there was an antibody response to p24. In addition, mice injected with the p24-hsp70 fusion

protein and mice injected with p24 alone produced a demonstrable T cell response.

Equivalents

Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described specifically herein. Such equivalents are intended to be encompassed in the scope of the following claims.